VACUUM DRYING OF COTTON
A Feasibility Study

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VACUUM DRYING OF COTTON

A Feasibility Study

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SUMMARY

Bench tests carried out at ambient temperatures showed that using reduced atmospheric pressure to dry cotton fiber to low moisture levels is feasible. The apparatus produced a barometric pressure of 5 millimeters (0.2 inch) of mercury within a bell jar after 10 minutes of pumping. After 10 minutes 66.6 percent of the moisture was removed from 1 gram of lint, but only 36.1 percent was removed from 3 grams of seed cotton. The data showed that essentially all moisture can be removed from cotton fibers after sufficient exposure in a vacuum dryer.

Continuous-flow experiments with a vacuum-drying apparatus operating at approximately 8 inches of mercury vacuum followed. The average seed-cotton moisture content decreased from 11.4 to 9.5 percent in one test series after 4 minutes of drying and from 7.8 to 6.3 percent in a second series after 8 minutes of drying. Statistically, these decreases were highly significant. For the condition of the experiments and the treatments used, no significant amount of moisture was removed from seed cotton for drying periods less than 2 minutes. Regression analysis showed that, in vacuum drying, a decrease in moisture contents is related to an increase in drying period by log $Y=a-bX$ (where Y=moisture content, X= exposure period, and a and b are constants based on experimental data). Changes in batt density did not significantly affect the amount of moisture removed.

Differences in cottonseed germination percentages among treatments were small and not significantly related to vacuum-drying period. Fiber test measurements showed no significant differences in 2.5-percent span length, uniformity ratio, or in fiber strength related to vacuum treatment.

FEASIBILITY OF VACUUM DRYING OF COTTON

The removal of moisture from hygroscopic products such as cotton may be described by the vapor pressure theory. This theory involves raising the vapor pressure

of moisture inside the products or decreasing the vapor pressure of the surrounding atmosphere to cause moisture movement from high to low pressure. The moisture evaporation rate is proportional to the pressure differential for continuously wetted surfaces, but in most agricultural products the time required for moisture to migrate from within the material to its surface will determine the evaporation rate.

The drying of cotton involves two major drying periods: the constant-rate period and the falling-rate period. The constant period is short and involves evaporation of moisture from the surface. This period ends at the moisture content that no longer maintains a flow rate to the surface equal to the maximum rate of surface evaporation under the drying conditions. The drying of most agricultural products starts in the falling-rate period. The falling-rate period includes two stages that are unsaturated surface drying and drying where the rate of water diffusion within the product is slow. The last stage controls the rate of evaporation.[1]

This rate of evaporation can be increased by using heated air to increase the vapor pressure inside the product. In addition, heated air has a greater moisture-carrying capacity than unheated air and is used in all cotton ginning plants to remove moisture from seed cotton before and during cleaning. The typical gin has two similar stages of drying, each stage exposing the cotton to heated air for approximately 10 seconds. In each stage seed cotton is fed into a heated air pipe, where it is transported by the air to a multishelf dryer and then to a separating cleaner. Temperature varies greatly in this type of drying system. When the burner temperature control is a simple ON-OFF switch, the temperature at the drying stage entrance varies from 160° to 325° F or even greater, as the burner cycles.

Studies of the cellulose cell and the complex physical structure of the cotton fiber have shown that when seed cotton is heavily dried and immediately put through the ginning process its fiber and spinning properties are adversely affected.[2]

In addition to causing heat damage to the cotton, this system

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[1] Chen, C. S., and Johnson, W. H. KINETICS OF MOISTURE MOVEMENT IN HYGROSCOPIC MATERIALS. 1. THEORETICAL CONSIDERATION OF DRYING PHENOMENA. Paper presented at annual meeting of Amer. Soc. Agr. Engin., Detroit, Mich., Dec. 12-15, 1967. (Paper No. 67–856.)

Hall, C. W. DRYING FARM CROPS. 336 pp. Ann Arbor, Mich. 1957.

[2] Franks, G. N., and Shaw, C. S. MULTIPATH DRYING AT COTTON GINS FOR CONTROLLING MOISTURE IN COTTON. U.S. Dept. Agr., Agr. Res. Serv. ARS 42–69, 12 pp. 1962.

Griffin, A. C., Jr., and Mangialardi, G. J. AUTOMATIC CONTROL OF SEED CONTROL OF SEED COTTON DRYING AT COTTON GINS, A REVIEW OF RESEARCH. U.S. Dept. Agr., Agr. Res. Serv. ARS 42–57, 14 pp. 1961.

requires a considerable investment in burners, fuel gas, shelf dryers, fans, pipes, and power.

Vacuum drying of freshly dug peanuts in batch-type ovens has shown that reducing the vapor pressure results in decreased moisture content. However, up to 47 hours at 20 inches of mercury vacuum were required at ambient temperature to reduce the moisture content from 30 to about 3 percent.[3]

The objectives of the work reported in this publication were to develop a means of drying cotton fibers without heat to be used as a control in fiber damage studies and to examine the feasibility of using partial-vacuum drying in commercial cotton ginneries.

PRELIMINARY INVESTIGATIONS

The first experiments were bench tests with a small vane-type mechanical vacuum pump evacuating a bell jar. Cotton for drying consisted of 3-gram specimens of seed cotton and 1-gram specimens of lint. Weight losses were observed by a telescope mounted on a micrometer that followed the deflection of a quartz spring supporting the specimen (fig. 1). These tests were carried out at ambient temperature (78° F).

The experiments showed that using reduced atmospheric pressure to dry fiber to low moisture levels is feasible (table 1). The apparatus produced a barometric pressure of 5 millimeters (0.2 inch) of mercury within a bell jar after 10 minutes of pumping and removed 66.6 percent of the moisture from a 1-gram lint sample and 36.1 percent from a 3-gram seed-cotton sample. This indicated that moisture is readily removed from lint, but longer periods are required for seed drying. The data showed that essentially all moisture can be removed from cotton fibers after sufficient vacuum-drying time.

As a result of the bell-jar experiments, greater quantities of seed cotton for ginning were dried. Vacuum chambers were fabricated from steel drums and military powder barrels, but these chambers developed air leaks during the tests so that the minimum pressure developed was not sufficient to give the desired degree of drying. An arrangement supporting 25 to 30 pounds of seed cotton on five layered shelves inside the barrels showed no benefit over single-mass tests. The apparatus was incapable of meeting the re-

[3] KUNZE, O. R., CLARK, L. E. ,and SORENSON, J. W. CONTINUOUS AND INTERMITTENT DRYING OF PEANUTS UNDER VACUUM. Paper presented at annual meeting of Amer. Soc. Agr. Engin., Detroit, Mich., Dec. 12-15, 1967. (Paper No. 57-855.)

MANBECK, H. B., NELSON, G. L., LYND, J. Q., and MASON, M. E. ANAEROBIC VACUUM TECHNIQUES FOR MYCOTOXIN—FREE PEANUT DRYING. Paper presented at annual meeting of Amer. Soc. Agr. Engin., Detroit, Mich., Dec. 12-15, 1967. (Paper No. 67-857.)

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FIGURE 1.—Bench model vacuum dryer showing quartz spring and telescope-micrometer arrangement. *Left to right*: Temperature recorder, telescope, bell jar, pressure indicator, and vacuum pump.

quirements, and this line of work was abandoned in favor of a continuous-flow, vacuum-drying apparatus.

CONTINUOUS-FLOW VACUUM DRYING

Experimental Apparatus

The continuous-flow vacuum dryer consisted of feed controller, inlet vacuum-sealing cylinder, vacuum-conditioning chamber, and outlet vacuum-sealing cylinder (fig. 2). A lobe-type rotary blower, single-stage without intercooling, served as the vacuum pump.[4] The vacuum blower rotated at 2,968 revolutions per minute and produced a chamber vacuum pressure of approximately 8 inches of mercury. The chamber temperature dropped approximately 2° F below ambient at startup, but rose and leveled at approximately 2° F above ambient because of the friction heat created by the vacuum-sealing cylinders. Ambient air volume introduced into the chamber through these cylinders during operation averaged 300 cubic feet per minute and was exhausted by the pump through a discharge silencer. During cotton processing, the chamber vacuum decreased somewhat as foreign matter and some cotton entered and partially blocked the in-line air filter located between the chamber and pump.

[4] WRIGHT, E. F., WISLICENUS, G. F., DISERENS, P., and others. PUMPS AND COMPRESSORS. Mechanical Engineering Handbook, section 14. 99 pp. New York. 1958.

TABLE 1.—*Effect of exposure period and barometric pressure on moisture content of seed cotton and lint (bell-jar experiments)*

Exposure period (min)	Bell-jar pressure (mm Hg)	Moisture content and percentage removed from—			
		Seed cotton		Lint	
		Content[1]	Amount removed[2]	Content[1]	Amount removed[2]
		Pct	*Pct*	*Pct*	*Pct*
0	760	9.13	—	6.53	—
1	375	8.51	6.8	5.45	16.5
2	167	7.97	12.7	4.79	26.6
3	89	7.54	17.4	4.44	32.0
4	44	7.17	21.5	4.08	37.5
5	24	6.80	25.5	3.65	44.1
6	14	6.48	29.0	3.28	49.8
7	9	6.28	31.2	2.94	55.0
8	7	6.10	33.2	2.67	59.1
9	6	5.91	35.3	2.24	65.7
10	5	5.83	36.1	2.18	66.6
12	5	5.68	37.8	2.00	69.4
14	5	5.56	39.1	1.83	72.0
16	5	5.38	41.1	1.57	76.0
20	5	5.15	43.6	1.00	84.7
25	5	5.00	45.2	.81	87.6
30	5	4.82	47.2	.71	89.1
35	5	4.60	49.6	.45	93.1
40	5	4.43	51.5	.20	96.9
45	5	4.30	52.9	.03	99.5

[1] Percentage of total sample weight.
[2] Percentage of moisture removed during vacuum drying.

The cotton batt was transported through the vacuum-conditioning chamber by three flexible steel conveyor belts. Agitating rollers, which had faster tip speeds than the conveying belts, reoriented the batt as it was transported between belts. Exposure time in the vacuum chamber was controlled by the speed of the conveyor belts. Calibration of the feed controller permitted setting desired rates of cotton feed. The batt depth was 3 inches and the width, 24 inches.

The apparatus was operated under the same conditions to process either seed cotton or lint. Although the lint was transported through the apparatus satisfactorily, some accumulated on the spiked agitating rollers and had to be removed.

Drying Procedure

Since the time allowed for moisture removal at cotton gins is limited, the first objectives were to develop an equation relating final

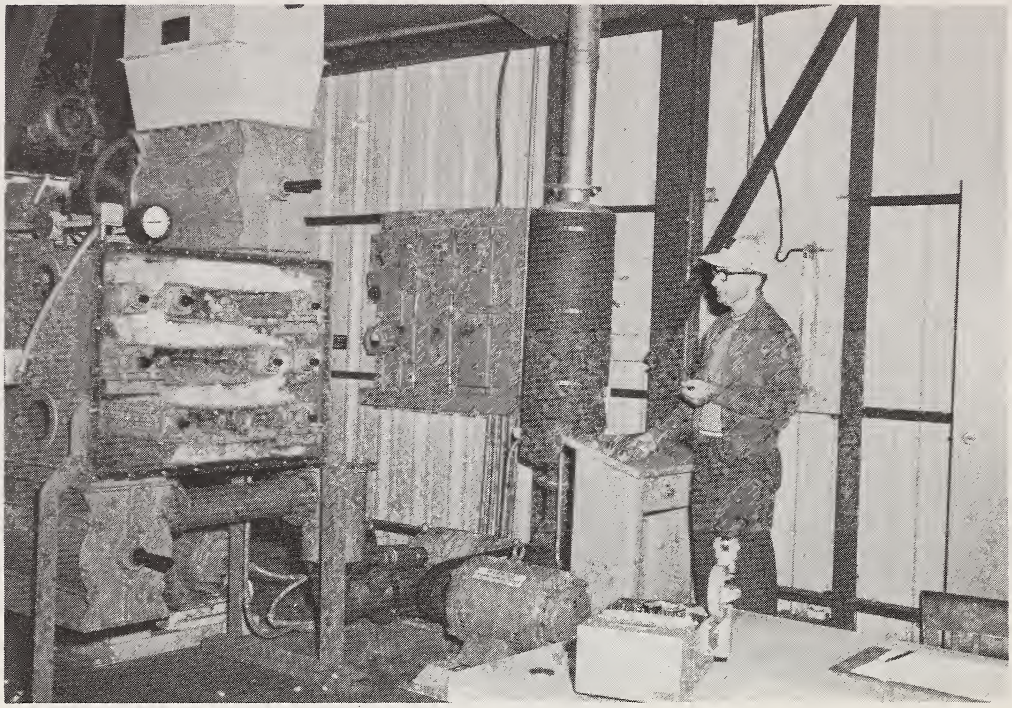

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FIGURE 2.—Partial-vacuum apparatus employed in continuous-flow drying experiments. *Left to right*: Vacuum dryer, discharge silencer (background), and Hartmeter (instrument on table in foreground).

moisture content to drying period and to examine the effect of rate of the cotton feed on the amount of moisture removed. Eight vacuum-drying periods, from 3.75 seconds to 8 minutes, plus a no-conditioning control, and three rates of cotton feed were investigated. In all, 244 15-pound seed-cotton test lots were processed. During processing, ambient temperature and relative humidity and vacuum chamber temperature and pressure were recorded continuously. No supplementary heat was used.

Cotton moisture contents were determined both electronically and by ovendrying.[5] Immediately following seed-cotton processing, a portion was ginned in a gin with 6-inch-diameter saws to obtain lint and seed for moisture analysis. Electronic measurements were made on 1.5-gram lint and 3-gram seed-cotton samples with a Hartmeter having a 1.75-inch-diameter electrode cup (instrument shown on table in fig. 2).

The data were subjected to analysis of variance and both

[5] AMERICAN SOCIETY FOR TESTING MATERIALS. STANDARD METHOD OF TEST FOR MOISTURE IN COTTON BY OVEN-DRYING. 1971 Annual Book of ASTM Standards, pt. 25, pp. 419-426. 1971.

linear and curvilinear regression analysis. Significant differences were established by Tukey's w-procedure.[6]

Results

Seed-cotton drying

Test series 1.—In test series 1, seed cotton was vacuum-dried for seven periods, from 3.75 seconds to 4 minutes. Drying at each period was replicated eight times. A batt density of 0.78 pound of seed cotton per cubic foot was maintained for all vaccum-drying periods (table 2). After 4 minutes seed-cotton moisture decreased significantly, from 11.4 to 9.5 percent, but no significant difference in moisture content occurred after short vacuum-drying periods. Similarly, lint-moisture content decreased from 9.6 to 8.8 percent after 4 minutes of drying.

[6] STEEL, R. G., AND TORRIE, J. H. PRINCIPLES AND PROCEDURES OF STATISTICS. 481 pp. New York. 1960.

The equilibrium lint-moisture content for the average ambient conditions during the test series was 10.6 percent. Therefore, it is likely that a greater amount of fiber moisture was removed during vacuum drying but was partly replenished while being processed in the 6-inch gin.

Change in seed-cotton and lint-moisture content with change in drying period appeared to be linear for the treatments used. Decrease in seed-cotton moisture content with increase in drying time produced the linear regression line $Y = 12.59 - 0.24X$ (where Y = moisture content with X = exposure period) with linear correlation coefficient r equal to -0.60. Decrease in lint-moisture content with increase in drying time gave the regression line $Y = 9.90 - 0.22X$ with $r = -0.71$. The correlation coefficient for the seed-cotton regression line was not significant statistically, whereas the coefficient for the lint regression line

TABLE 2.—*Moisture content of cotton dried for various periods in a partial vacuum (test series 1)*[1]

Test item	Control	Vacuum-drying period 3.75 s	7.5 s	15 s	30 s	1 min	2 min	4 min
	Pct	*Pct*	*Pct*	*Pct*	*Pct*	*Pct*	*Pct*	*Pct*
Seed cotton:								
Electronic method	11.4	11.1	11.3	11.4	11.3	11.3	10.9	9.5
Oven method	12.0	12.7	12.3	12.4	12.5	13.3	12.3	11.3
Lint	9.6	9.8	10.0	9.7	9.5	10.3	9.7	8.8
Cottonseed	13.3	13.6	13.9	13.4	13.5	14.4	14.1	13.2

[1] Each percentage is the average of 8 replications.

was significant at the 5-percent level. For longer vacuum-drying periods, the relationship probably would be curvilinear and might better fit the logarithmic curve log $Y=a-bX$ or the exponential $Y=ab^x$.

Test series 2.—The second test series involved 16 replications for each vacuum-drying time and gave more consistent results (table 3). It also included a longer drying period, and feed-rate effects were investigated. As in test series 1, a constant batt density of 0.78 pound of seed cotton per cubic foot was maintained for each vacuum-drying period.

Measured by the electronic method, seed-cotton moisture content decreased significantly after the 2 minutes of vacuum drying. There was no significant decrease in moisture content after vacuum-drying periods shorter than 2 minutes. Seed-cotton moisture decreased from 7.8 to 6.3 percent after 8 minutes of drying. Statistically, there was a significant decrease in the seed-moisture content as a result of increasing the drying period to 8 minutes. However, no significant seed-moisture changes were attributed to the shorter drying periods.

Lint-moisture content decreased from 6.9 to 6.0 percent as a result of increasing the drying time to 8 minutes, a highly significant change; the decrease in moisture content after the other drying periods was not significant. As in test series 1, a greater amount of fiber moisture probably was removed during drying but was partly replenished during processing in the 6-inch gin. (See "Lint-Cotton Drying.")

Changes in seed-cotton and lint-moisture content with increasing drying time were fitted to the curvilinear regression line log $Y=a-bX$ (a and b are constants based on experimental data) (fig. 3). Curvilinear correlation coefficients r for seed cotton (oven),

TABLE 3.—*Moisture content of cotton dried for 6 periods in a partial vacuum (test series 2)*[1]

Test item	Control	Vacuum-drying period (min)					
		0.25	0.50	1	2	4	8
	Pct	*Pct*	*Pct*	*Pct*	*Pct*	*Pct*	*Pct*
Seed cotton:							
Electronic method	7.8	7.6	7.6	7.5	7.2	6.7	6.3
Oven method	8.8	8.8	8.8	8.5	8.6	8.3	8.1
Lint	6.9	6.8	6.8	6.9	6.6	6.4	6.0
Cottonseed	9.4	9.3	9.7	9.8	9.6	9.3	9.2

[1] Each percentage is the average of 16 replications.

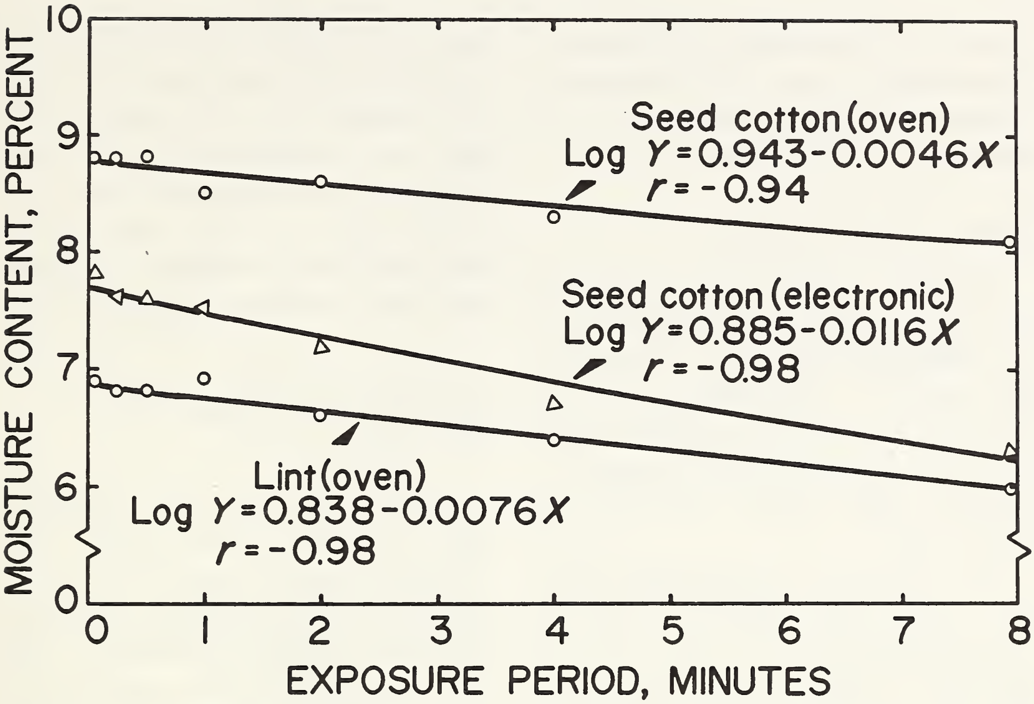

FIGURE 3.—Effect of vacuum-drying period on cotton-moisture content (test series 2).

seed cotton (electronic), and lint (oven) were —0.94, —0.98, and —0.98, respectively, and these values were all significant at the 1-percent level. Thus, the objective of developing an equation for the process was accomplished.

The effect of batt densities of 0.39, 0.78, and 1.56 pounds of seed cotton per cubic foot was studied (table 4). The chamber conveyor belt speed was such that a vacuum-drying period of 30 seconds was maintained for all batt densi-

TABLE 4.—*Moisture content of cotton, vacuum-dried for 30 seconds at 3 batt densities (test series 2)*[1]

Test item	Seed-cotton batt density (lb/ft^3)		
	0.39	0.78	1.56
	Pct	*Pct*	*Pct*
Seed cotton:			
Electronic method	7.7	7.6	7.4
Oven method	8.6	8.8	8.7
Lint	6.6	6.8	6.6
Cottonseed	9.5	9.7	9.4

[1] Each percentage is the average of 16 replications.

ties. No significant cottonseed, seed-cotton, or lint-moisture changes were attributed to changes in batt density.

Lint-cotton drying

Another experiment involved the processing of ginned lint cotton through the vacuum-drying apparatus in six replications for each of six exposure periods. Batt density was controlled at approximately 0.42 pound of lint per cubic foot.

The electronic measuring method showed the moisture level decreasing from 6.8 to 5.2 percent as the drying period increased from 0 to 8 minutes (table 5). Decreases in lint moisture were highly significant after the 2-minute drying period. Equilibrium lint-moisture content for outside ambient conditions during vacuum processing averaged 7.8 percent.

The decrease in lint-moisture content with increasing drying time was fitted to the curvilinear regression line log $Y = a - bX$ (fig. 4). Correlation coefficients r for the lines obtained by electronic and oven-measuring methods were −0.97 and −0.95, respectively. Both coefficients were statistically significant at the 1-percent level.

Seed germination and fiber tests

Seed-cotton that had been vacuum processed in test series 2 at various exposure periods was collected for later ginning to obtain samples for seed-germination and fiber testing. The lots were allowed to come to moisture equilibrium with the atmosphere and then were subjected to a ginning machinery sequence consisting of extractor feeder, 20-saw gin stand, and press.

Differences in cottonseed germination among vaccum-drying periods were not significant statistically, ranging from 66 to 76 per-

TABLE 5.—*Moisture content of lint cotton dried for 5 periods in a partial vacuum* [1]

Measurement method	Control	Vacuum-drying period (min)				
		0.50	1	2	4	8
	Pct	*Pct*	*Pct*	*Pct*	*Pct*	*Pct*
Electronic	6.8	6.4	6.3	6.1	5.6	5.2
Oven	7.0	6.6	6.6	6.6	6.2	5.9

[1] Each percentage is the average of 6 replications.

cent (table 6). Fiber lengths, as determined by the Digital Fibrograph, were not significantly different in 2.5-percent span length or uniformity ratio. Fiber bundle strength differences attributable to exposure period were also small and not significant.

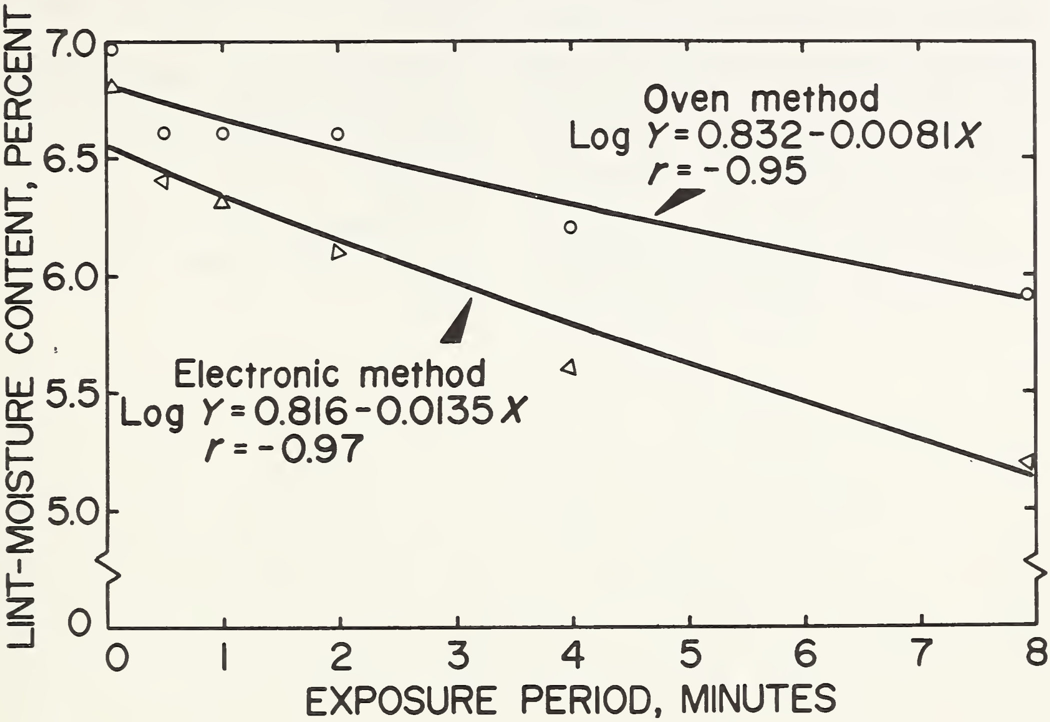

FIGURE 4.—Effect of vacuum-drying period on lint-moisture content.

TABLE 6.—*Cottonseed germination and fiber length and strength of samples after vacuum drying for 6 periods (test series 2)*[1]

Test item	Control	Vacuum-drying period (min) 0.25	0.50	1	2	4	8
Cottonseed germination, pct	66	68	74	72	70	76	67
Fiber length, inches:							
2.5-percent span length	1.18	1.19	1.18	1.19	1.19	1.19	1.18
50-percent span length	0.54	0.55	0.55	0.55	0.55	0.55	0.54
Uniformity ratio, pct	46	46	46	46	46	46	46
⅛-inch gage strength, grams per tex	23.6	23.7	23.7	23.8	23.8	23.7	23.8

[1] Each figure is the average of 16 replications.

CONCLUSIONS

The results show that vacuum drying can be used to remove moisture from cotton in research investigations, but that the procedure is too slow to be practicable in ginneries. If vacuum drying of cotton at gins is to become feasible, modification of the tested system is required, including—

1. Raising the vapor pressure of the moisture with supplementary heat to hasten evaporation.

2. Providing greater agitation of seed cotton, thus exposing more individual locks.

3. Redesigning the seed-cotton feeding cylinders to prevent ambient air from entering the chamber.

4. Modifying the air discharge so that only a minimum of foreign matter can be pulled into the suction filter.

5. Redesigning the ginning system to allow longer drying periods.

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